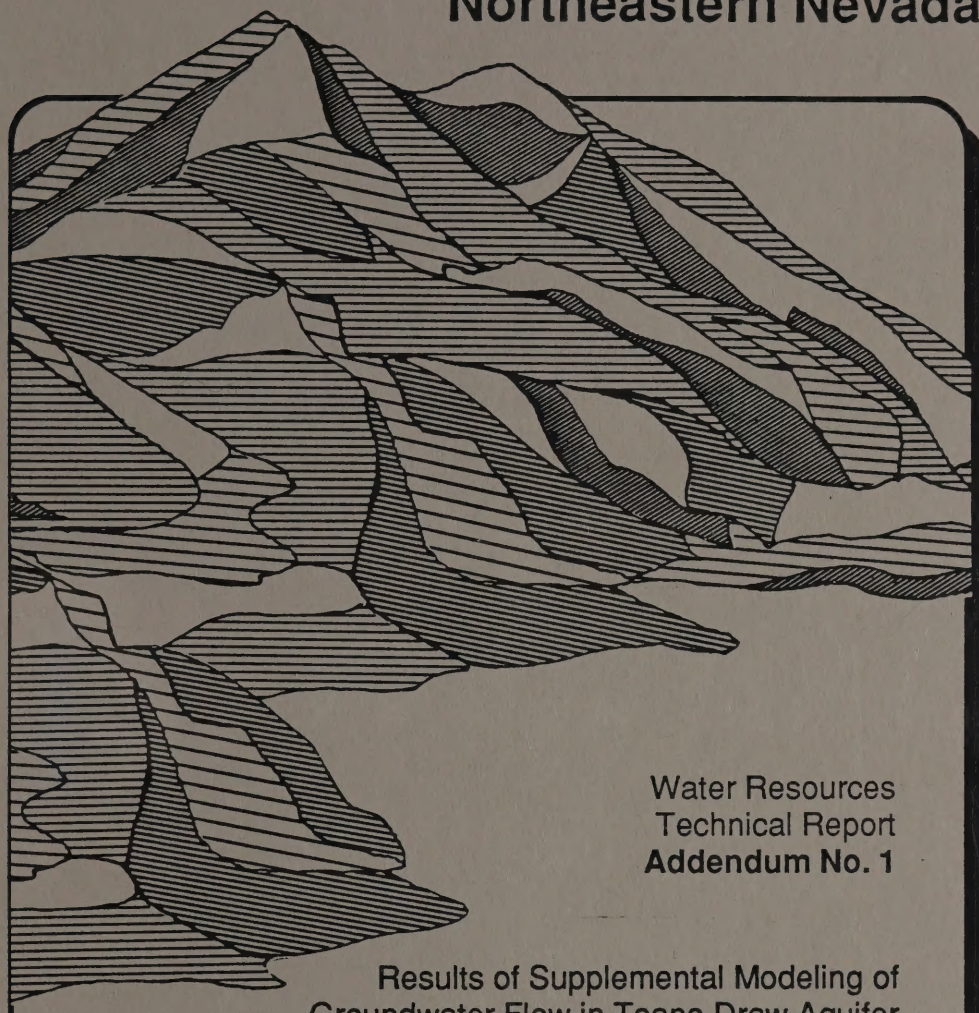
BLM LIBRARY
88077003

Draft Environmental Impact Statement
Thousand Springs Power Plant
Northeastern Nevada



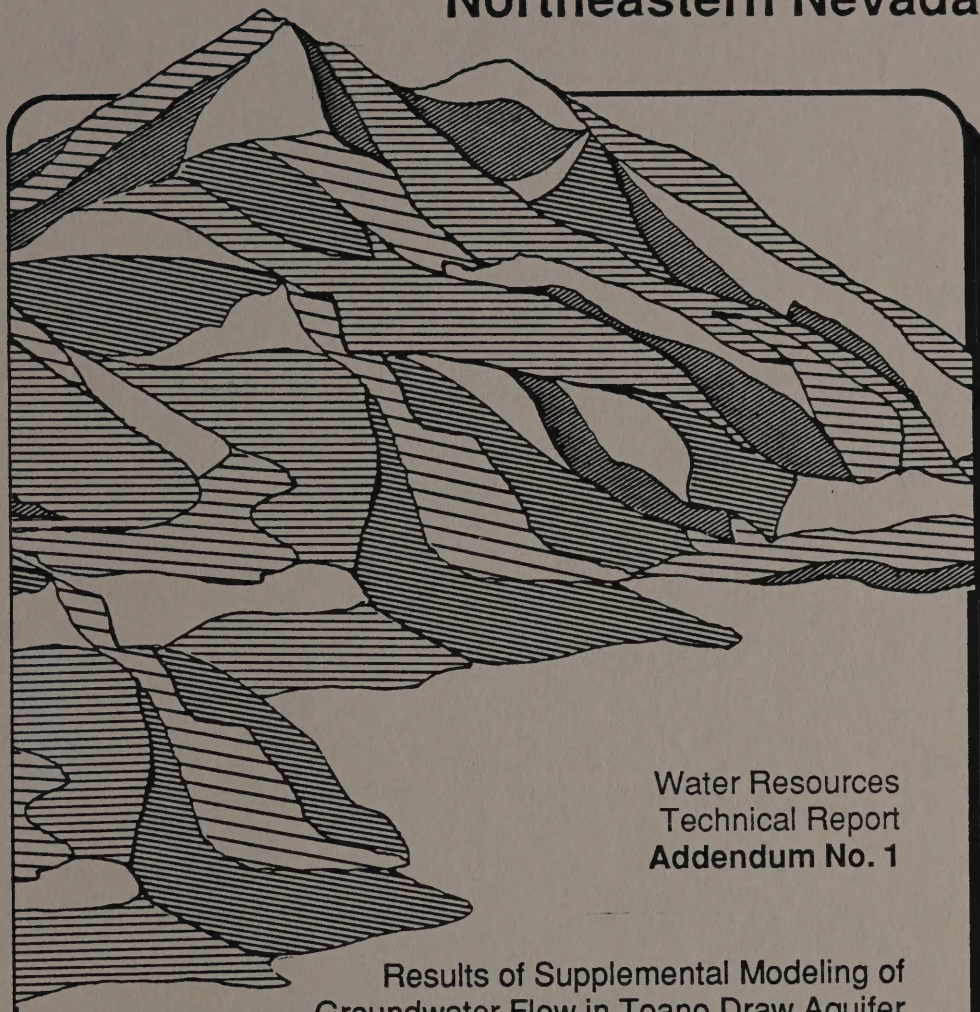
Water Resources
Technical Report
Addendum No. 1

Results of Supplemental Modeling of
Groundwater Flow in Toano Draw Aquifer

U.S. Department of the Interior
Bureau of Land Management
Elko District Office
Elko, Nevada

TD
195
.E4
W381
1990b

Draft Environmental Impact Statement
Thousand Springs Power Plant
Northeastern Nevada



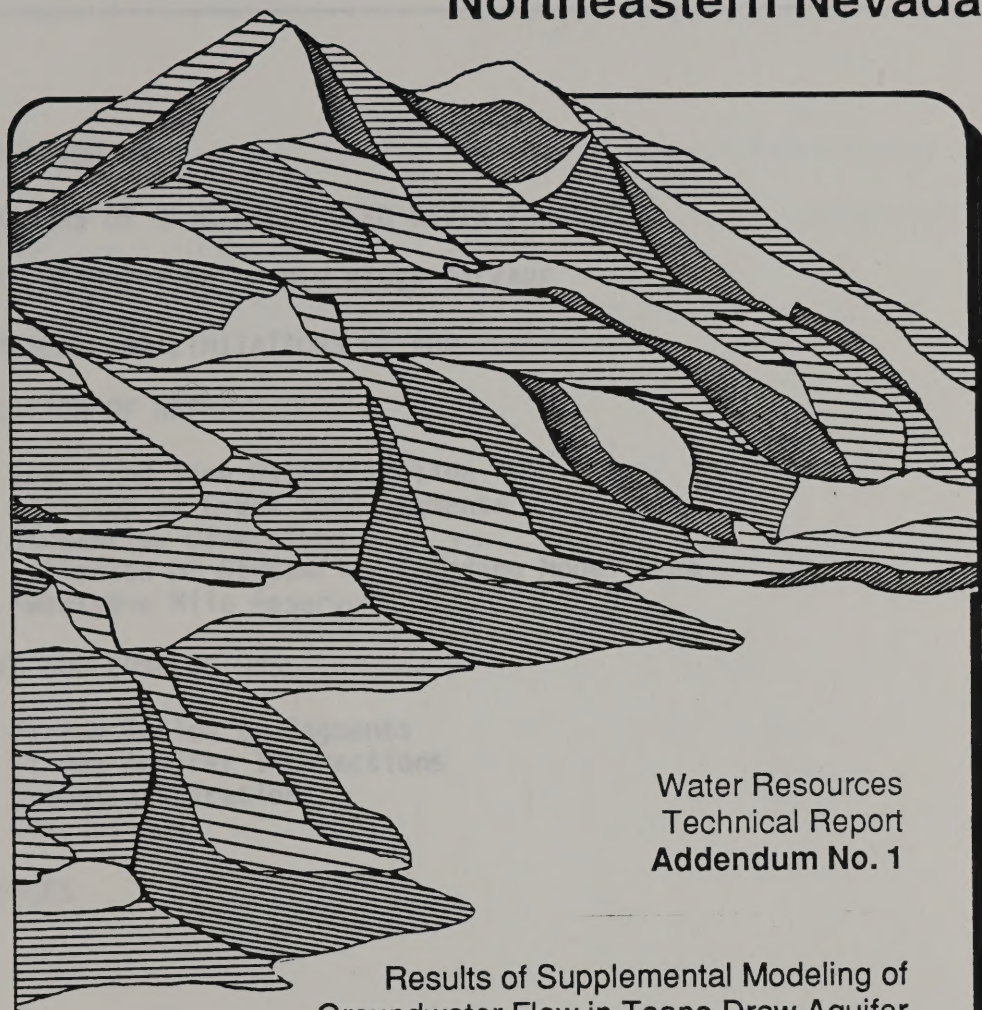
Water Resources
Technical Report
Addendum No. 1

Results of Supplemental Modeling of
Groundwater Flow in Toano Draw Aquifer

U.S. Department of the Interior
Bureau of Land Management
Elko District Office
Elko, Nevada

#1253689434
88077003
TD
195
.E4
W381
1990b

Draft Environmental Impact Statement
Thousand Springs Power Plant
Northeastern Nevada



Water Resources
Technical Report
Addendum No. 1

Results of Supplemental Modeling of
Groundwater Flow in Toano Draw Aquifer

U.S. Department of the Interior
Bureau of Land Management
Elko District Office
Elko, Nevada

TABLE OF CONTENTS

Section	Page
INTRODUCTION	1
LIMITATIONS OF ORIGINALLY USED RIVER PACKAGE	2
SUMMARY DESCRIPTION OF NEW RIVER PACKAGE	3
ASSUMPTIONS AND LIMITATIONS OF NRP	4
APPLICATION OF NRP	6
Space and Time Discretization	7
Division of Creek into Segments	8
Streamflow Diversions	8
Estimates of Streamflow Entering Model Area	10
Twentyone Mile Reservoir	12
RESULTS AND CONCLUSIONS	15
Stream Inflow to Segments	16
Stream-Aquifer Interactions	18
Evapotranspiration	21
Conclusions	22
REFERENCES	24

LIST OF TABLES

Table		Page
1	ESTIMATED RANGE OF AVERAGE SEASONAL FLOWS BY STREAM SEGMENT	25
2	DECREASES IN TOTAL AVERAGE FLOW IN CREEK AND IN GROUNDWATER DISCHARGE TO CREEK	26
3	DECREASE IN EVAPOTRANSPIRATION (ET) FROM AREAS OF SHALLOW WATER TABLE	27

LIST OF FIGURES

Figure		Page
1	SIMULATED STREAMFLOW ENTERING SEGMENTS	28
2	SIMULATED GROUNDWATER DISCHARGE TO SEGMENT I	29
3	SIMULATED GROUNDWATER DISCHARGE TO SEGMENT IIa	30
4	SIMULATED GROUNDWATER DISCHARGE TO SEGMENT IIb	31
5	SIMULATED GROUNDWATER DISCHARGE TO SEGMENT III	32
6	SIMULATED DECLINE IN GROUNDWATER DISCHARGE TO THE CREEK	33
7	SIMULATED EVAPOTRANSPIRATION RATE IN SEGMENT I	34
8	SIMULATED EVAPOTRANSPIRATION RATE IN SEGMENT IIa	35
9	SIMULATED EVAPOTRANSPIRATION RATE IN SEGMENT IIb	36
10	SIMULATED EVAPOTRANSPIRATION RATE IN SEGMENT III	37
11	SIMULATED DECLINE IN ET RATE	38

INTRODUCTION

This addendum presents the results of supplemental numerical modeling of groundwater flow in the Toano Draw aquifer. The modeling summarized in the Draft Environmental Impact Statement (DEIS), Thousand Springs Power Plant, Northeastern Nevada, (January 1990) and discussed in the accompanying Water Resources Technical Report, Volume I, (WRTR) was performed utilizing a modular, quasi-three-dimensional, finite difference model (MODFLOW, version 3.0 by McDonald and Harbaugh, 1988). That model consisted of several subroutine programs (packages). However, the river package of that model was not capable of progressively calculating the mass balance for flows along each reach of Thousand Springs Creek as the creek was subdivided in the modeled domain. Application of the model, therefore, required certain assumptions and the exercise of judgment in interpreting the results, i.e., making sure the computed aquifer recharge from or discharge to the creek was compatible with the streamflow data.

Following review of the Draft Water Resources Technical Report, the Nevada State Office of the U.S. Geological Survey (USGS) advised WCC, October 1989, that the USGS had just published a new streamflow routing package, developed by Prudic (1989), that is capable of simulating the mass balance of flow in each reach of a stream as the flow progresses down the stream. That package had been developed with the intent that it could be easily added to the MODFLOW model. However, the computer program for the new package was not received by WCC in time to add it to the model, run the model, and include the results in the DEIS. That package has now been received, added to the model, and additional simulations run as reported herein. It is noted that addition of the new river routing routine to the MODFLOW model did not significantly change the basic conclusions of the original modeling work, although it did refine the estimates of flows in

the various reaches of Thousand Springs Creek as considered in the domain of the model. This addendum to the Water Resources Technical Report presents the results of the additional modeling in terms of the changes in flow between the creek and the aquifer, and the reduction in evapotranspiration (ET) losses from areas having a shallow water table, as a result of pumping the Toano Draw aquifer for the operating life of the power plant.

The analyses reported here pertain to the pumping scenario described as Case 2b in the WRTR. This scenario is the proposed action as described in the DEIS. Because the conclusions derived from the additional modeling were not significantly different from the conclusions based on the original modeling, it was considered not necessary to perform the additional modeling for the other water development scenarios considered in the WRTR.

LIMITATIONS OF ORIGINALLY USED RIVER PACKAGE

As discussed in the WRTR, a river package included with the MODFLOW model was used to evaluate stream-aquifer interactions. A major limitation of that river package was that it did not have a streamflow accounting routine, and as such it was not capable of tracking the flow in the stream at any point in time and at any location. Instead, the river package required presetting the depth of water in the stream, and this depth remained constant instead of varying to account for flows to or from the aquifer.

For a stream providing aquifer recharge, the model's inability to account for the amount of flow available in the stream could indicate higher water losses from the stream than the flow actually available in the stream. Keeping the depth of water in the stream constant, without adjusting it to reflect flow in the stream, could result in overestimation or underestimation of the stream-aquifer interactions, unless the stream were very wide, in which case relatively large changes in flow would result in only small changes in water depth. For example, for a stream providing

the various reaches of Thousand Springs Creek as considered in the domain of the model. This addendum to the Water Resources Technical Report presents the results of the additional modeling in terms of the changes in flow between the creek and the aquifer, and the reduction in evapotranspiration (ET) losses from areas having a shallow water table, as a result of pumping the Idaho Brew aquifer for the operating life of the power plant.

The analyses reported here pertain to the pumping scenario described as Case 3b in the WRTR. This scenario is the proposed action as described in the DEIS. Because the conclusions derived from the additional modeling were not significantly different from the conclusions based on the original modeling, it was considered not necessary to perform the additional modeling for the other water development scenarios considered in the WRTR.

LIMITATIONS OF ORIGINALLY USED RIVER PACKAGE

As discussed in the WRTR, a river package included with the MODFLOW model was used to evaluate stream-aquifer interactions. A major limitation of that river package was that it did not have a streamflow accounting routine, and as such it was not capable of tracking the flow in the stream at any point in time and at any location. Instead, the river package required prescribing the depth of water in the stream, and this depth remained constant instead of varying to account for flows to or from the aquifer.

For a stream providing aquifer recharge, the model's inability to account for the amount of flow available in the stream could indicate higher water losses from the stream than the flow actually available in the stream. Keeping the depth of water in the stream constant, without adjusting it to reflect flow in the stream, could result in overestimation or underestimation of the stream-aquifer interactions, unless the stream were very wide, in which case relatively large changes in flow would result in only small changes in water depth. For example, for a stream providing

aquifer recharge (an influent stream), assuming a constant water depth would result in overestimating the water losses from the stream. Hence, in using the old river package, care was needed in interpreting the model results and particular consideration was given in evaluating available flow in the stream. In the WRTR, the limitations of the old river package were recognized and model results were interpreted accordingly.

The objective of this addendum is to present the results of using a more refined river package, that overcomes some of the limitations of the old river package, to re-evaluate the stream-aquifer interactions. For consistency, the new river package (NRP) had to be compatible with the MODFLOW numerical model used in the original WRTR analysis.

The following sections discuss the reasons for selecting the new river package for the analysis, the approach used to evaluate the stream-aquifer interactions, the assumptions made to adapt the package to the specific conditions of the model domain, and the results and conclusions of the additional analyses.

SUMMARY DESCRIPTION OF NEW RIVER PACKAGE

The NRP developed by Prudic (1989) was selected and applied to re-evaluate the stream-aquifer interactions between the aquifer in the model area (Toano Draw Subbasin) and Thousand Springs Creek. This NRP overcomes some of the limitations of the originally used river package provided with the MODFLOW model by McDonald and Harbaugh (1988). The NRP is fully compatible with MODFLOW. The NRP has a streamflow accounting routine that keeps track of the water available in various reaches of a stream at any point in time. Where there are flow diversions from the stream, or flow additions to the stream from tributaries, the NRP is capable of simulating the effects of the diversions and additions. Given the width, slope and roughness coefficient of the stream channel, the NRP uses Manning's formula to estimate the depth of water in a stream reach based on the flow entering the reach.

aquifer recharge (an influent stream), assuming a constant water depth would result in overestimating the water-losses from the stream. Hence, in using the old river package, care was needed in interpreting the model results and particular consideration was given in evaluating available flow in the stream. In the WRPM, the limitations of the old river package were recognized and model results were interpreted accordingly.

The objective of this addendum is to present the results of using a more refined river package, that overcomes some of the limitations of the old river package, to re-evaluate the stream-aquifer interactions. For consistency, the new river package (NRP) had to be compatible with the MODFLOW numerical model used in the original WRPM analysis.

The following sections discuss the reasons for selecting the new river package for the analysis, the approach used to evaluate the stream-aquifer interactions, the assumptions made to adapt the package to the specific conditions of the model domain, and the results and conclusions of the additional analyses.

SUMMARY DESCRIPTION OF NEW RIVER PACKAGE

The NRP developed by Prudic (1989) was selected and applied to re-evaluate the stream-aquifer interactions between TAM aquifer in the Sonoma area (Lower Crow Subbasin) and Thousand Springs Creek. This NRP overcomes some of the limitations of the originally used river package provided with the MODFLOW model by McDonald and Harbaugh (1988). The NRP is fully compatible with MODFLOW. The NRP has a streamflow accounting routine that keeps track of the water available in various reaches of a stream at any point in time. Where there are flow diversions from the stream, or flow additions to the stream from tributaries, the NRP is capable of simulating the effects of the diversions and additions. Given the width, slope and roughness coefficients of the stream channel, the NRP uses Manning's formula to estimate the depth of water in a stream reach based on the flow during the reach.

For the purpose of the discussions below, it is necessary to distinguish between a stream segment and a stream reach as used in the NRP. A segment is a length of stream channel in which contributions to streamflow, from one or more surface sources, is added at the upstream end of the segment, or in the case of diversions from the stream subtracted at the downstream end of the segment. A reach is the part of a segment that corresponds to an individual cell in the finite-difference grid used to simulate groundwater flow in an aquifer. A segment may consist of one or more reaches.

ASSUMPTIONS AND LIMITATIONS OF NRP

To use the NRP, it is necessary to understand the inherent limitations and the assumptions required to incorporate the streamflow accounting routine in MODFLOW, as discussed below.

a) The package does not account for the time of travel within the stream. Thus, the model assumes that streamflow entering the model area is instantly available in downstream reaches for each specified period in the model simulation. This assumption is reasonable because groundwater flow rates are usually very small compared to streamflow rates. Also groundwater simulation timesteps are usually in months or years whereas changes in streamflow along a stream course are usually in days. Accordingly, the streamflow data input to the model are the estimated averages for the groundwater timesteps.

b) The cross section of the stream is assumed to be rectangular, with a stream width much greater than the depth of water in the channel. Within the model area, the available cross sections of Thousand Springs Creek (Appendix C-1, WRTR), indicate the creek has relatively flat side slopes, averaging about 5:1 (5 horizontal to 1 vertical) and a bottom width of about 4 feet. For the typical average annual flow in Thousand

Springs Creek, the estimated depth of water in the creek is about 1 foot. A one foot depth of water in a trapezoidal channel with a bottom width of a few feet and 5:1 side slopes may be approximated by a rectangular channel about 10 feet wide. Hence in the model, Thousand Springs Creek was assumed to be a 10 feet wide rectangular channel. The relatively shallow water depth in comparison to the width of channel satisfies the assumptions made in the NRP.

c) Stream bed conductance values, used to calculate leakage between a stream reach and the underlying aquifer, are assumed to be constant during a stress period and do not change with the flow or the stream stage.

d) Leakage from the stream to the aquifer is assumed to be instantaneous. This assumption may be unreasonable in situations where the thickness of the unsaturated zone, between the creek bottom and the water table surface, is large. Within the section of Thousand Springs Creek traversing the model area, water levels in the aquifer are generally higher than the water level in the creek. The maximum drawdown in the aquifer beneath the creek, due to case 2b pumping (12,000 ac-ft/yr of pumping from a well field located in the south central portion of the model area), is about 5 feet. Hence, any unsaturated zone that may be created, due to lowering of the water table beneath the stream bed, probably will be less than 5 feet. The assumption of instantaneous leakage may, therefore, not be seriously violated.

e) The NRP assumes that stream-aquifer interactions are principally in a vertical direction, and Darcy's law is used to evaluate these interactions. The evaluation of stream-aquifer interactions by a one-dimensional equation to represent vertical flow may be valid when there is a distinct, relatively impermeable layer separating the stream from the underlying aquifer. The hydrogeologic characterization of the

Springs Creek, the estimated depth of water in the creek is about 1 foot. A few feet depth of water in a trapezoidal channel with a bottom width of a few feet and 5:1 side slopes may be approximated by a rectangular channel about 10 feet wide. Hence in the model, Thousand Springs Creek was assumed to be a 10 feet wide rectangular channel. The relatively shallow water depth in comparison to the width of channel satisfies the assumptions made in the MRP.

c) Stream bed conductance values, used to calculate leakage between a stream reach and the underlying aquifer, are assumed to be constant during a stress period and do not change with the flow or the stream stage.

d) Leakage from the stream to the aquifer is assumed to be instantaneous. This assumption may be unreasonable in situations where the thickness of the unsaturated zone, between the creek bottom and the water table surface, is large. Within the section of Thousand Springs Creek bounding the model area, water levels in the aquifer are generally higher than the water level in the creek. The maximum drawdown in the aquifer beneath the creek, due to a 25 gpm pumping (12,000 gallons of pumping from a well field located in the south central portion of the model area), is about 5 feet. Hence, any dewatered zone that may be created, due to lowering of the water table beneath the stream bed, probably will be less than 5 feet. The assumption of instantaneous leakage may, therefore, not be seriously violated.

e) The MRP assumes that stream-aquifer interactions are principally in a vertical direction, and Darcy's law is used to evaluate these interactions. The evaluation of stream-aquifer interactions by a one-dimensional equation to represent vertical flow may be valid when there is a distinct, relatively impermeable layer separating the stream from the underlying aquifer. The hydrogeologic characterization of the

aquifer beneath and adjacent to Thousand Springs Creek indicates that the sedimentary deposits are highly stratified, and variable in thickness and grain size on a small scale. The logs of monitoring wells MW-1 and TW-1 show the presence of semi-pervious clay and pervious gravel layers beneath the creek. The presence of semi-pervious layers will induce flow exchange between the aquifer and the creek to be effectively vertical, and a one-dimensional analysis may be justified. In addition, the limited available data on flows in the creek do not justify using a two or more dimensional analysis of the stream-aquifer interactions.

f) If there is an irrigation flow diversion from a stream segment and the flow entering the segment during a modeling timestep is less than the required diversion the NRP code does not allow the diversion to be effected. For the purposes of this analysis, the NRP code was modified to allow for 90 percent of the available flow entering a stream segment to be diverted for those times when the flow entering the segment was less than the full requirement for irrigation. This change in the code was made so as to make the analysis conservative. However, if the flow entering the segment exceeded the programmed irrigation diversion from the segment, the full diversion was permitted to take place.

APPLICATION OF NRP

In this section, the procedures used to estimate stream-aquifer interactions are discussed. This discussion includes space and time discretization, division of Thousand Springs Creek into segments, streamflow diversions, estimation of streamflow entering the model area, and how the presence of a reservoir on the creek was treated.

Space and Time Discretization

The spatial discretization, as used in the original modeling effort (see Figure 8-2, WRTR), was also used in this analysis. Temporal simulation, on an annual basis, was divided into irrigation and non-irrigation periods. The irrigation period was assumed to extend from April through September, during which streamflow diversions from Thousand Springs Creek were made. The non-irrigation period was assumed to extend from October through March, during which time no diversions were made from the creek. Two time steps, with an interval of 3 months per time step, were used for each period. The total simulation time was 49 years.

It is noted that for all of the numerical modeling that has been done, both as reported in the DEIS and the WRTR, and as reported in this addendum, it was assumed that irrigation uses of available surface water would continue essentially as at present throughout the simulation period. Accordingly, the modeling results indicate the drawdowns expected to occur with no curtailment of surface water uses for irrigation plus withdrawal of the power-plant water requirements from the Toano Draw aquifer to supply three generating units. The estimated present net consumptive use of surface water by irrigated agriculture within the model area is a maximum of about 8000 ac-ft/yr. This use is on an as-available basis, and is in addition to the 12000 ac-ft/yr maximum power plant use from the Toano Draw aquifer. It is noted that the modeling did not include an assumption that deficiencies in surface water supplies for irrigation uses would be satisfied by pumping groundwater. There presently is no significant use of groundwater for irrigation within Segments I and II. Groundwater is used for irrigation in segment III, even though the surface water supply in that segment generally exceeds the irrigation requirements within that segment. This is because ground water is preferred to surface water in the type of irrigation (high pressure sprinkler systems) practiced on the lands alongside Thousand Springs Creek in Segment III. The assumption of continuing irrigation uses of surface water within the model

area is conservative, since the proposed action includes curtailment of irrigation uses of water when the results of aquifer water level monitoring indicate that drawdown effects are occurring in the vicinity of Thousand Springs Creek.

Division of Creek into Segments

Review of data on irrigation in the valley of Thousand Springs Creek indicated that there were diversions of flow at several locations along the creek within the model area. Even though the total aggregate diversions from the creek had been estimated (see Table 4-5, WRTR), the exact locations of the diversions were not known. Based on the information on irrigation diversions provided by the U.S. Soil Conservation Service, Elko, Nevada, the creek was divided into three segments, from each of which significant irrigation diversions took place. The first segment extended from the western boundary of the model area to Shores; the second segment extended from Shores to Twentyone Mile Reservoir; and the third segment extended from Twentyone Mile Reservoir to the eastern boundary of the model area.

Streamflow Diversions

All known diversions from the creek are for irrigation purposes. The estimates of the amount of water diverted from each segment were based on the acreage irrigated from the creek. The estimates of irrigated acreage within each segment, and the amount of irrigation water consumptively used in each segment, were based on data provided by the U.S. Soil Conservation Service, Elko Nevada.

As mentioned above, the exact locations of the irrigation diversions were not known. Therefore, to be conservative, is was assumed that all diversions within a segment occurred at the upstream end of the segment. In the simulation the quantity of water diverted from each segment, as

input to the model, was either the net consumptive use within the segment, when the flow was equal to or greater than the total irrigation requirements, or 90 percent of the available flow when the flow was less than the irrigation requirement. The diverted water was not allowed to return to the creek or recharge the aquifer. Instead, it was assumed to remain within a dummy cell to which it was diverted, making the simulation equivalent to the evapotranspiration (ET) losses from the irrigated lands in the segment. The river bottom conductance of the dummy cell was set equal to zero so as to prohibit interactions between the diverted flow and the aquifer.

It is noted that in practice more water is actually diverted for irrigation then is consumptively used. The excess diverted water either percolates to groundwater or returns to the creek. Inputting to the model only the net consumptive use in each segment was equivalent to instantaneous return flow to the creek of the excess diverted flows.

Since all of the diversions from the creek were assumed to be for irrigation, it was further assumed that all the diversions occurred in the period April through September of each water year. No flow diversions were allowed for the rest of the water year, i.e., October through March. If the flow entering a stream segment during any period was less than the net irrigation requirement in that segment, it was assumed that 90 percent of the flow entering the segment during the period was diverted, and the remaining 10 percent of the flow discharged from the downstream end of the segment.

The estimated streamflow diversions (in million cubic feet per day), when sufficient flow was available in the creek, were 1.3, 0.2 and 0.37 in segments I, II, and III, respectively. These diversions were assumed to be constant throughout the timestep being simulated.

input to the model, was either the net consumptive use within the segment, when the flow was equal to or greater than the total irrigation requirements, or 90 percent of the available flow when the flow was less than the irrigation requirements. The diverted water was not allowed to return to the creek or recharge the aquifer. Instead, it was assumed to remain within a dummy cell to which it was diverted, making the simulation equivalent to the evapotranspiration (ET) losses from the irrigated lands in the segment. The river bottom conductance of the dummy cell was set equal to zero so as to preclude interactions between the diverted flow and the aquifer.

It is noted that in practice more water is actually diverted for irrigation than is consumptively used. The excess diverted water either percolates to groundwater or returns to the creek. Inputting to the model only the net consumptive use in each segment was equivalent to instantaneous return flow to the creek of the excess diverted flows.

Since all of the diversions from the creek were assumed to be for irrigation, it was further assumed that all the diversions occurred in the period April through September of each water year. No flow diversions were allowed for the rest of the water year, i.e., October through March. If the flow entering a stream segment during any period was less than the net irrigation requirement in that segment, it was assumed that 90 percent of the flow entering the segment during the period was diverted, and the remaining 10 percent of the flow discharged from the downstream end of the segment.

The estimated streamflow diversions (in million cubic feet per day), when sufficient flow was available in the creek, were 1.3, 0.2 and 0.37 in segments 6, 11, and 111, respectively. These diversions were assumed to be constant throughout the timeseries being simulated.

Estimates of Streamflow Entering Model Area

There were no long term, continuous records of streamflow available for Thousand Springs Creek. The U. S. Geological Survey provided approximately three years of continuous streamflow data from the Wilkins gage (March 1985 to December 1987) and two years of data from the Shores gage (March 1985 to October 1986). Also, Chilton Engineering measured flows in the creek at various times between February 1982 and October 1983, and also between February 1986 and October 1988. Collectively, the available record of flow in the creek was not adequate for characterizing long term flow in the creek. However, there were 35 years of continuous and concurrent precipitation data available from the Wells, Contact and Montello monitoring stations. Making the simplifying assumption that streamflow is generally proportional to precipitation, the long term precipitation data were used to estimate long term streamflow characteristics in the creek. The assumption of streamflow being proportional to precipitation may be reasonable on an annual or longer term basis but probably not for shorter periods. In this analysis, it was assumed that the annual streamflow in Thousand Springs Creek at Wilkins was proportional to the annual precipitation at Contact. It was further assumed that the 35 year record of precipitation would be representative of future precipitation in the area.

In Section 6 of the WRTR, the average annual streamflow at Wilkins was estimated to be about 12,500 ac-ft/yr. To use precipitation data for estimating streamflows, the long term annual mean precipitation was calculated from the 35 years of record. The annual precipitation data were then normalized by dividing annual precipitation by the mean. The normalized annual precipitation was then multiplied by the estimated mean annual steamflow at Wilkins (12,500 ac-ft/yr) to obtain the estimated annual streamflows at Wilkins. Since only 35 years of precipitation data were available, and model simulation time was 49 years, the generated annual streamflow cycle was assumed to repeat after 35 years. It is noted that the mean precipitation for the 14-year period (1949 through 1962) that

was used a second time in projecting long-term flow in the creek was less than the mean for the 35 year period of record at Contact, i.e., 8.88 versus 10.17 inches per year. Therefore, the assumption of a repeating cycle, as used in the analysis, was considered conservative.

Based on the limited period of measured streamflows at Wilkins, it was estimated that about 60 to 70 percent of the annual streamflow generally occurs during the period October through March, while 30 to 40 percent occurs during April through September. To be conservative it was assumed that 70 percent of annual streamflow occurs during October through March, and 30 percent occurs during April through September. The assumption of only 30 percent of annual flow being available April through September results in only limited water being available in the creek after subtracting irrigation diversions. This was considered a conservative assumption for this analysis.

In the model, only the streamflow entering the model area from outside sources needs be specified. Within the model area, the possible flow sources that may contribute significant flow to Thousand Springs Creek are Rock Springs Creek and Toano Draw. Numerous other minor tributaries entering Thousand Springs Creek within the model domain are assumed to contribute minor or insignificant amounts to the average total flows in Thousand Springs Creek. Concurrent measurements of streamflows in Rock Springs and Thousand Springs creeks, by Chilton Engineering, indicated that flow in Rock Springs Creek (at its confluence with Thousand Springs Creek) was always much less than the flow in Thousand Springs Creek at Eccles Narrows. Eccles Narrows was the nearest flow measurement station on Thousand Springs Creek to the confluence of Rock Springs Creek and Thousand Springs Creek. During the Chilton monitoring period, Toano Draw was practically always dry. The contributions of flow from Rock Springs Creek and Toano Draw to Thousand Springs Creek were therefore considered to be negligible in the analysis.

Twentyone Mile Reservoir

Twentyone Mile Reservoir is an irrigation storage reservoir located on Thousand Springs Creek, near the confluence of Twentyone Mile Draw with the Creek. There is no continuous record of storage in this reservoir, although it is known that in most years it does not fill, and at the end of the irrigation season it frequently is empty. The reservoir has an estimated active storage capacity of about 6800 ac-ft. It has an unregulated spillway at 5190 feet elevation, and a regulated discharge pipe with inlet at about 5156 feet elevation.

The new river package does not include a routine for routing flows through a reservoir. Accordingly, several assumptions and modifications to the river package were made for this analysis to account for the reservoir. Because of the lack of data on the reservoir storage history the assumptions and modifications resulted in a simplistic treatment of the reservoir. However, it is believed that the treatment was conservative. Further, because the reservoir is relatively far from, and significantly lower in elevation, than the proposed Toano Draw wellfield, it is expected that the reservoir will have little or no effect on the wellfield, or aquifer drawdown resulting from the pumping.

Chilton Engineering, in conjunction with the streamflow measurement program they conducted in 1982-83 and 1986-88, estimated that total average unregulated discharge passing the dam, and appearing as surface water below the dam, when there was no flow through the spillway, was about 5 cubic feet per second. This discharge included significant leakage through the control valve on the outlet pipe when the valve was in the closed position and there was water in the reservoir. This valve has since been repaired.

The major assumptions adopted for this analysis are summarized as follows:

- Average flow past the dam, and appearing as surface water downstream from the dam, was 5 cubic feet per second throughout the year. During the non-irrigation season this flow was comprised of leakage through, under and around the dam, and unregulated spillway releases. During the irrigation season, the flow was comprised of regulated releases through the outlet works and leakage past the dam. Although flows exceeding 5 cfs downstream from the dam are not infrequent, the inherent assumption that these excess flows do not contribute significantly to aquifer recharge is considered conservative.

- During the non-irrigation season--October through March--stored water in the reservoir would provide significant head above the original, natural bottom of the stream channel through the reservoir area. The channel bottom was considered likely to be approximately coincident with the maximum natural water table elevation in the area. The head due to stored water in the reservoir would cause aquifer recharge rates to be greater than along other reaches of the stream. Because the available records were not adequate for calculating an approximate reservoir water surface elevation that would be representative of average conditions, a value of elevation 5180 ft was selected for the modeling. This elevation corresponds approximately to one-half the storage capacity of the reservoir. Therefore, aquifer recharge from the reservoir, during the non-irrigation season, was related to a 26-foot head (5180-5156) instead of the 1-foot head estimated to be generally applicable to all other reaches of the stream. An independent check of the sensitivity of the stream aquifer interactions to the reservoir water surface elevation was conducted. In this analysis, the reservoir was assumed to be full (El 5190 ft) during the non-irrigation season and empty during the irrigation season. The results of the simulations showed that the reservoir elevation mainly influenced the stream aquifer interactions in the vicinity of the reservoir (stream

segment IIb). Using a reservoir water surface at elevation 5190 ft indicates a groundwater recharge rate of about 2.5 cfs as opposed to a 1.5 cfs recharge rate if the reservoir water surface elevation is 5180 ft. However, the indicated impacts of power plant pumping (case 2b, WRTR) on the stream aquifer interactions were not sensitive to the reservoir water surface elevation. The assumed reservoir elevation (El 5180 ft) was considered to be reasonable and conservative.

It is noted that the assumptions of a reservoir filled to one-half its capacity for the entire non-irrigation season, and empty throughout the entire irrigation season, introduces discontinuities into the mass balance computations for streamflow between segments II and III. Absent data on actual long-term streamflow and reservoir storage, manipulation of model input data to mechanically eliminate the discontinuities would not be expected to improve our understanding of groundwater dynamics within the model domain. The average streamflow values input to the model, based on the Contact precipitation data, were generally large enough to be consistent with the assumption that the reservoir would, on the average, be about one-half full (about 3000 ac-ft) throughout the non-irrigation season. The assumption that the reservoir would be essentially empty throughout the irrigation season implies that the water stored in the reservoir during the non-irrigation season would be released over a short time interval at the beginning of the irrigation season, which would not be consistent with reality. However, the 5 cfs that is believed to be always available at the upstream end of segment III exceeds the net irrigation requirements of the segment. Therefore, in the simulation the reservoir releases during the irrigation season that would exceed 5 cfs were assumed to simply flow across the segment without significantly affecting the stream-aquifer interactions.

- During the irrigation season--April through September--no significant quantity of water was stored in the reservoir, and the

segment III). Using a reservoir water surface as elevation 5100 ft indicates a groundwater recharge rate of about 2.5 cfs as opposed to a 1.5 cfs recharge rate if the reservoir water surface elevation is 5180 ft. However, the indicated impacts of power plant pumping (case 2b, WRTM) on the stream aquifer interactions were not sensitive to the reservoir water surface elevation. The assumed reservoir elevation (E) 5180 ft) was considered to be reasonable and conservative.

It is noted that the assumptions of a reservoir filled to one-half its capacity for the entire non-irrigation season, and empty throughout the entire irrigation season, introduces discontinuities into the mass balance computations for streamflow between segments II and III. Absent data on actual long-term streamflow and reservoir storage, manipulation of model input data to mechanically eliminate the discontinuities would not be expected to improve our understanding of groundwater dynamics within the model domain. The average streamflow values input to the model, based on the Contact prediktation data, were generally large enough to be consistent with the assumption that the reservoir would, on the average, be about one-half full (about 3000 ac-ft) throughout the non-irrigation season. The assumption that the reservoir would be essentially empty throughout the irrigation season implies that the water stored in the reservoir during the non-irrigation season would be released over a short time interval at the beginning of the irrigation season, which would not be consistent with reality. However, the 5 cfs that is believed to be always available at the upstream end of segment III exceeds the net irrigation requirements of the segment. Therefore, in the simulation the reservoir releases during the irrigation season that would exceed 1 cfs were assumed to simply flow across the segment without significantly affecting the stream-aquifer interactions.

During the irrigation season (April through September--20 significant quantity of water was stored in the reservoir, and the

reservoir would not contribute to aquifer recharge at a rate differing from the rate along the other reaches of the creek, i.e., the recharge rate upstream from the dam varied as the natural flow in the creek, or as a direct function of the depth of flow in the stream channel. There generally is water in the reservoir at the beginning of the irrigation season, and this water is released, on an as-available basis, to satisfy irrigation requirements. However, it is understood the reservoir frequently is essentially empty a few months before the end of the irrigation season. Therefore, the assumption of an empty reservoir during the irrigation season, as being representative of the head driving aquifer recharge in the reservoir area, is considered reasonable and conservative.

RESULTS AND CONCLUSIONS

During the course of interpreting the model simulations, it was found convenient to consider stream segment II as subdivided into two segments (segments IIa and IIb) because the stream-aquifer interactions in the two segments are quite different. Segment IIa extends from Shores to Eccles Narrows and segment IIb extends from Eccles Narrows through Twentyone Mile Reservoir.

The division of segment II into two subsegments was only to enhance the presentation and discussion of model results--it was not used in the model simulations. Within segment IIa, the creek appears to receive flow from the aquifer while within segment IIb the creek appears to be recharging the aquifer.

To estimate the impact of pumping on flows in Thousand Springs Creek, and evapotranspiration rates within the model area, the model was initially run with no pumping in the basin for a period of 49 years. The model was then run again with an assumed pumping schedule as follows:

Years of Plant Operation	Pumping Rate Acre-Feet/Year
1,2	4000
3-14	8000
15-35	12000
36,37	8000
38-49	4000

All pumping was from one well field in the south part of Toano Draw Subbasin (case 2b of WRTR). The difference in stream-aquifer interactions between the no pumping and pumping simulations was assumed to be the impact of pumping. During each of these simulations, flow in Thousand Springs Creek entering the model area was made to vary with precipitation, as discussed previously.

Stream Inflow to Segments

The range of the variations in the simulated streamflow entering the various segments of Thousand Springs Creek throughout the period of power plant operation are listed in Table 1 and the pattern of the variations is indicated in Figure 1. Please note that the intent of Figure 1 is to indicate an expected characteristic pattern for the variation in flows, based on the 35 year record of precipitation at Contact. Three-month time steps were used in the modeling throughout the simulation period, whereas the data plotted in Figure 1 (and following figures) were limited to the model outputs at alternating 2-year and 3-year timesteps, respectively, except for the first and last years of the simulation.

During the irrigation season of each year (April through September), the streamflow entering a stream segment was net of irrigation diversions from the segment. The streamflow entering a segment was also the outflow from the segment immediately upstream, except for the flow between segments IIb and III where the assumed program of storage in and releases from

Twentyone Mile Reservoir, as discussed above, introduced discontinuities into the mass balance calculations.

Throughout most of the simulation period, flow entering segments I and II during the irrigation season was less than the net irrigation water requirements in the respective segments, and therefore, very little flow entered the two segments during those periods--i.e., 90 percent of the total flow was assumed diverted at the upstream end of each segment. The streamflow in each segment during the irrigation season was mainly from groundwater discharge to the creek.

It is noted that the simulated streamflow entering segment II, at the Shores streamflow gaging station, during the first year of simulation was approximately 7800 ac-ft/yr which is in good agreement with the estimated average value of 8100 ac-ft/yr obtained using the streamflow generation model (WRTR, Section 6.0). Also, the assumed streamflow entering the model area through the west boundary, in the first year of simulation, was equal to the estimated long-term average annual streamflow at Wilkins--i.e., 12,500 ac-ft/yr.

In segment III, the average flow during the irrigation season downstream from Twentyone Mile Reservoir, was assumed to be leakage past the dam plus flow through the outlet pipe with inlet at the approximate elevation of the reservoir bottom. During the non-irrigation season the flow entering segment III was unregulated spillway releases plus leakage past the dam. For both seasons the average flow was assumed to be constant at 0.432m cu ft/day (5 cfs). After subtracting the irrigation water requirements (.373m cu ft/day or 4 cfs), the flow entering segment III during the irrigation season was estimated to be a constant of about .06m cu ft/day (less than 1 cfs). Average flow leaving segment III and the model area during non-irrigation seasons was estimated to be 0.722m cu ft/day (8.4 cfs) and during the irrigation season, the outflow was estimated to be about .36m cu ft/day (4.2 cfs).

Twentyone Mile Reservoir, as discussed above, introduced discontinuities into the mass balance calculations.

Throughout most of the simulation period, flow entering segments I and II during the irrigation season was less than the net irrigation water requirements in the respective segments, and therefore, very little flow entered the two segments during those periods--i.e., 90 percent of the total flow was assumed diverted at the upstream end of each segment. The streamflow in each segment during the irrigation season was mainly from groundwater discharge to the creek.

It is noted that the simulated streamflow entering segment II, at the Eaton-streamflow gaging station, during the first year of simulation was approximately 7800 ac-ft/yr which is in good agreement with the estimated average value of 8100 ac-ft/yr obtained using the streamflow generation model (WRIR, Section 6.0). Also, the assumed streamflow entering the model area through the west boundary, in the first year of simulation, was equal to the estimated long-term average annual streamflow in Milliken--i.e., 12,500 ac-ft/yr.

In segment III, the average flow during the irrigation season downstream from Twentyone Mile Reservoir was assumed to be leakage past the dam plus flow through the outlet pipe with inlet at the approximate elevation of the reservoir bottom. During the non-irrigation season the flow entering segment III was unregulated spillway releases plus leakage past the dam. For both seasons the average flow was assumed to be constant at 0.42Cm cu ft/day (5 cfs). After subtracting the irrigation water requirements (.37Cm cu ft/day or 4 cfs), the flow entering segment III during the irrigation season was estimated to be a constant of about .05m cu ft/day (less than 1 cfs). Average flow leaving segment III and the model area during non-irrigation seasons was estimated to be 0.22Cm cu ft/day (2.4 cfs) and during the irrigation season, the outflow was estimated to be about .18m cu ft/day (6.2 cfs).

On an annual basis, streamflow in Thousand Springs Creek leaving the model area, near the confluence of Crittenden Creek and Thousand Springs Creek, was simulated to be essentially constant at about 4600 ac-ft/yr, which is similar to the average value of 5100 ac-ft/yr obtained using the streamflow generation model (WRTR, Section 6). The simulation did indicate a minor decline (about 0.1 cfs) in the flow from segment III due to reduced aquifer discharge to the creek as a result of the water table being lowered by pumping for the power plant water requirement.

Stream-Aquifer Interactions

The estimates of groundwater discharge to Thousand Springs Creek in segments I, IIa, IIb and III are shown in Figures 2 through 5, respectively. In these figures, a positive discharge implies flow from the aquifer to the creek and a negative discharge implies flow from the creek to the aquifer. These plots indicate significant year-to-year variations in groundwater discharge to the creek without the Power Plant Project, and similar variations are expected after the power plant starts operating. Generally, groundwater discharge to the creek is greater during irrigation seasons then non-irrigation seasons because flows in the creek generally are less during the irrigation season and therefore the water depth in the creek also is less during those seasons.

Figure 2 indicates that pumping for the power plant would not have any significant effect on the stream-aquifer interactions in Segment I until after pumping is initiated to supply a third generation unit from the Toano Draw aquifer--i.e., 14 years after initial pumping to supply the first generating unit. Thereafter, the groundwater discharge to the creek decreases progressively to the end of the simulation period. The maximum decline in groundwater discharge to the creek in this segment would be approximately 0.1m cu ft/day (1.1 cfs). Although Figure 2 indicates that the change in the discharge of groundwater, from the aquifer to the creek

On an annual basis, streamflow in Thousand Springs Creek leaving the model area, near the confluence of Crystalline Creek and Thousand Springs Creek, was simulated to be essentially constant at about 4600 ac-ft/yr, which is similar to the average value of 5100 ac-ft/yr obtained using the streamflow generation model (SWTM, Section 6). The simulation did indicate a minor decline (about 0.1 cfs) in the flow from segment III due to reduced aquifer discharge to the creek as a result of the water table being lowered by pumping for the power plant water requirement.

Stream-Aquifer Interactions

The estimates of groundwater discharge to Thousand Springs Creek in segments I, IIa, IIb and III are shown in Figures 2 through 5, respectively. In these figures, a positive discharge implies flow from the aquifer to the creek and a negative discharge implies flow from the creek to the aquifer. These plots indicate significant year-to-year variations in groundwater discharge to the creek without the Power Plant Project, and similar variations are expected after the power plant starts operating. Generally, groundwater discharge to the creek is greater during irrigation seasons than non-irrigation seasons because flows in the creek generally are less during the irrigation season and therefore the water depth in the creek also is less during these seasons.

Figure 2 indicates that pumping for the power plant would not have any significant effect on the stream-aquifer interactions in Segment I until after pumping is initiated to supply a third generation unit from the Lower Oreo aquifer--i.e., 14 years after initial pumping to supply the first generating unit. Thereafter, the groundwater discharge to the creek decreases progressively to the end of the simulation period. The maximum decline in groundwater discharge to the creek in this segment would be approximately 0.1m cu ft/day (1.1 cfs). Although Figure 2 indicates that the change in the discharge of groundwater from the aquifer to the creek

along segment I, amounts to approximately one-half of the no-project discharge, this is not considered significant relative to the total average surface water inflow to the creek, which is about 17 cfs. It should be noted that during the pumping period, the water table would drop below the level of the creek in a few locations, particularly in the vicinity of Wine Cup Ranch, because of aquifer drawdown.

For segment IIa, the simulation indicates flow from the creek to the aquifer in all years during non-irrigation seasons (relatively high streamflow periods) while the reverse would appear to occur in most years during irrigation seasons (low streamflow periods). This is because during non-irrigation seasons, the depths of water in the creek would be higher than the simulated water table elevation of the underlying aquifer and the creek therefore would act as a recharge source to the aquifer. Conversely, during irrigation seasons, the water level in the creek would be lower than the underlying water table elevation and therefore, the aquifer would discharge to the creek.

Figure 3 indicates that the effects of pumping would not be significant in segment IIa until after about 25 years of pumping. Because of the relatively large distance between segment IIa and the Toano Draw wellfield, the effects of pumping on this segment of the creek would be smaller than the effects on segment I. The maximum change in groundwater discharge to the creek due to pumping would be about 5000 cu ft/day (less than 0.1 cfs).

Twentyone Mile Reservoir is located at the downstream end of segment IIb. As explained above, for simulation purposes, the water level in the reservoir was set at elevation 5180 ft during non-irrigation seasons. During irrigation seasons, the reservoir was assumed to be empty. Based on those assumptions, the model simulations indicate (Figure 4) that the creek would be recharging the aquifer during non-irrigation seasons while the opposite would be true during irrigation seasons. Maximum flow from the creek to the aquifer would be about 0.15m cu ft/day (1.7 cfs) and the

along segment I, amounts to approximately one-half of the no-project discharge, thus is not considered significant relative to the total average surface water inflow to the creek, which is about 17 cfs. It should be noted that during the pumping period, the water table would drop below the level of the creek in a few locations, particularly in the vicinity of Wine Cup Ranch, because of aquifer drawdown.

For segment IIa, the simulation indicates flow from the creek to the aquifer in all years during non-irrigation seasons (relatively high streamflow periods) while the reverse would appear to occur in most years during irrigation seasons (low streamflow periods). This is because during non-irrigation seasons, the depths of water in the creek would be higher than the simulated water table elevation of the underlying aquifer and the creek therefore would act as a recharge source to the aquifer. Conversely, during irrigation seasons, the water level in the creek would be lower than the underlying water table elevation and therefore, the aquifer would discharge to the creek.

Figure 3 indicates that the effects of pumping would not be significant in segment IIa until after about 25 years of pumping. Because of the relatively large distance between segment IIa and the Toano Draw wellfield, the effects of pumping on this segment of the creek would be smaller than the effects on segment I. The maximum change in groundwater discharge to the creek due to pumping would be about 5000 cu ft/day (less than 0.1 cfs).

Twenty-one Mile Reservoir is located at the downstream end of segment IIb. As explained above, for simulation purposes, the water level in the reservoir was set at elevation 5180 ft during non-irrigation seasons. During irrigation seasons, the reservoir was assumed to be empty. Based on these assumptions, the model simulations indicate (Figure 4) that the creek would be recharging the aquifer during non-irrigation seasons while the opposite would be true during irrigation seasons. Maximum flow from the creek to the aquifer would be about 0.15m cu ft/day (1.7 cfs) and the

maximum groundwater discharge to the creek during irrigation seasons would be about 0.07m cu ft/day (1 cfs). The decline in stream-aquifer interactions during the simulation period was estimated to be about 2000 cu ft/day (0.02 cfs).

Figure 5 indicates that there would be no significant effects of power plant water withdrawals in segment III until about 25 years after the start of pumping. Groundwater discharge to the creek would decline progressively from about year 25 to the end of the simulation period. However, the maximum decline in groundwater discharge to the creek due to pumping would be only about 0.01m cu ft/day (0.1 cfs).

The estimated decreases in groundwater discharge to the various segments of the creek due to power plant pumping are summarized in Figure 6. As would be expected, segment I would be affected the most, where the net decrease in groundwater discharge would be about 900 ac-ft/yr. This is followed by segment III which would have a decrease of about 80 ac-ft/yr. The total decrease in groundwater discharge to all segments of the creek was estimated to be about 1000 ac-ft/yr.

Table 2 summarizes the decrease in groundwater discharge to the creek by segment and also the decrease expressed as percentages of the pre-pumping groundwater discharge to the creek and the total flow in the creek. The greatest change would occur in segment I, where the decrease would be about 48 percent in the groundwater discharge to the creek and 10 percent in average streamflow. In segment IIa, the decrease in groundwater discharge to the creek would be about 31 percent and there would be about 1 percent reduction in average streamflow. Segment IIb would not be significantly affected by the pumping while segment III would have a decrease of about 4 percent in both groundwater discharge and streamflow.

Evapotranspiration

Figures 7 through 10 show the estimates of evapotranspiration (ET) losses during the simulation period, by stream segment, from areas where the water table surface is near the ground surface--i.e., phreatophyte ET. The estimates are presented for the simulation runs based on both no pumping and pumping for the power plant project. The figures indicate that the estimated phreatophyte ET losses are not constant even with no pumping for the power plant. Pumping for the power plant would lower the water table sufficiently to reduce the phreatophyte ET losses from all four segments, as considered in this discussion, but mostly from segments I and IIa. Figure 11 summarizes the changes in ET rates, by stream segment, expected to occur as a result of power plant pumping.

Generally, the simulation indicates that evapotranspiration rates would be slightly higher during non-irrigation seasons than during irrigation seasons. This is probably because, during non-irrigation seasons, water levels in the creek are relatively high and more water infiltrates from the creek to the adjacent shallow-water-table aquifer.

In segment I, the initial evapotranspiration rate is estimated to be 0.2m cu ft/day (2.3 cfs) and the reduction due to pumping at the end of the pumping period is 0.017m cu ft/day (0.2 cfs). The initial evapotranspiration rate in segment IIa is estimated to be .074m cu ft/day (0.8 cfs). Reduction in evapotranspiration rate in Segment IIa due to pumping is estimated to be 9000 cu ft/day (0.1 cfs). Segment IIb shows no measurable decline in evapotranspiration rate due to power plant pumping while segment III shows an estimated decline of 8200 cu ft/day (0.1 cfs).

Table 3 shows the percentage decline in evapotranspiration rate in each segment with respect to the average pre-project evapotranspiration rate in the segment. The highest impacted segments are I and IIa with declines in evapotranspiration rates of 9 percent and 12 percent respectively.

Evapotranspiration

Figures 7 through 10 show the estimates of evapotranspiration (ET) losses during the simulation period, by stream segment, from areas where the water table surface is near the ground surface--i.e., phreatophyte ET. The estimates are presented for the simulation runs based on both no pumping and pumping for the power plant project. The figures indicate that the estimated phreatophyte ET losses are not constant even with no pumping for the power plant. Pumping for the power plant would lower the water table sufficiently to reduce the phreatophyte ET losses from all four segments, as considered in this evaluation, but mostly from segments I and IIa. Figure 11 summarizes the changes in ET rates, by stream segment, expected to occur as a result of power plant pumping.

Generally, the simulation indicates that evapotranspiration rates would be slightly higher during non-irrigation seasons than during irrigation seasons. This is probably because, during non-irrigation seasons, water levels in the creek are relatively high and more water infiltrates from the creek to the adjacent shallow-water-table aquifer.

In segment I, the initial evapotranspiration rate is estimated to be 0.24 cu ft/day (2.3 cfs) and the reduction due to pumping at the end of the pumping period is 0.012m cu ft/day (0.2 cfs). The initial evapotranspiration rate in segment IIa is estimated to be .0144 cu ft/day (0.8 cfs). Reduction in evapotranspiration rate in segment IIa due to pumping is estimated to be 3000 cu ft/day (0.1 cfs). Segment IIb shows no measurable decline in evapotranspiration rate due to power plant pumping while segment III shows an estimated decline of 8200 cu ft/day (0.1 cfs).

Table 3 shows the percentage decline in evapotranspiration rate in each segment with respect to the average pre-project evapotranspiration rate in the segment. The highest impacted segments are I and IIa with declines in evapotranspiration rates of 9 percent and 12 percent respectively.

Conclusions

The results of the flow modeling discussed above indicate that pumping to supply three power plant units, at up to 12,000 ac-ft/yr, from a well field in the southern part of Toano Draw, would reduce groundwater discharge to Thousand Springs Creek, especially along segments I and III. The impacts, however, are considered to be relatively small in relation to the average flow in the creek and the magnitude of the natural fluctuations in streamflow.

The simulations indicate that the power plant pumping would not significantly impact flows in the creek during non-irrigation seasons, but there would be modest decreases in flow in the creek during irrigation seasons.

The simulations are consistent with present conditions in that, even without pumping for the power plant, there are times when there is no flow in the creek, because all of the flow is diverted for irrigation. Based on the simulations, it seems likely that the water table would drop below the level of the creek bottom in the vicinity of the Winecup Ranch due to aquifer pumping for the power plant. Even though a water table decline may occur in the Winecup Ranch vicinity, the aquifer probably would continue to provide net flow to the creek downstream thereof throughout the period of power plant operation.

The total estimated reduction in groundwater discharge to the creek, based on the simulations using the NRP, would be about 1000 ac-ft/yr. Most of the decrease would occur upstream from Shores (segments I and IIa/). This estimate is not importantly different from the estimate of 1500 ac-ft/yr obtained using the original river package. The net reduction in groundwater discharge to the creek would be substantially less than the consumptive use of water by irrigated agriculture along Thousand Springs Creek upstream from Twentyone Mile Reservoir--about 6000 ac-ft/yr.

Conclusions

The results of the flow modeling discussed above indicate that pumping to supply three power plant units, at up to 12,000 ac-ft/yr, from a well field in the southern part of Long Draw, would reduce groundwater discharge to Thousand Springs Creek, especially along segments I and III. The impacts, however, are considered to be relatively small in relation to the average flow in the creek and the magnitude of the natural fluctuations in streamflow.

The simulations indicate that the power plant pumping would not significantly impact flows in the creek during non-irrigation months, but there would be some decreases in flow in the creek during irrigation seasons.

The simulations are consistent with present conditions in that, even without pumping for the power plant, there are times when there is no flow in the creek, because all of the flow is diverted for irrigation. Based on the simulations, it seems likely that the water table would drop below the level of the creek bottom in the vicinity of the Wilscoby Ranch due to pumping for the power plant. Even though a water table decline may occur in the Wilscoby Ranch vicinity, the aquifer probably would continue to provide net flow to the creek consistent throughout the period of power plant operation.

The total estimated reduction in groundwater discharge to the creek, based on the simulations using the MPP, would be about 1000 ac-ft/yr. Most of the decrease would occur upstream from Shores (segments I and IIA). This estimate is not importantly different from the estimate of 1300 ac-ft/yr obtained using the original river package. The net reduction in groundwater discharge to the creek would be substantially less than the consumptive use of water by irrigated agriculture along Thousand Springs Creek upstream from Twentyone Mile Reservoir--about 6000 ac-ft/yr.

There were no significant changes in the estimated impacts that would occur along Thousand Springs Creek as a result of the additional simulation modeling that was done using the NRP from the impacts estimated by using the old river package. The error of the estimates by both methods probably are greater than the differences in the estimates based on the two packages.

REFERENCES

Chilton Engineering. 1982-1988. Hydrologic Monitoring Thousand Springs Creek for Woodward-Clyde Consultants, Inc.; Elko, Nevada.

McDonald, M.G., and A.W. Harbaugh. 1988. A Modular Three-Dimensional Finite-Difference Ground-Water Flow Model, Modeling Techniques, Book 6, Chapter A1.

Prudic, David E. 1989. Documentation of a Computer Program to Simulate Stream-Aquifer Relations Using a Modular, Finite-Difference, Ground-Water Flow Model, U.S. Geological Survey, Open-File Report 88-729.

U.S. Geological Survey. 1985-87. Water Resources Data, Nevada, U.S. Geological Survey Water-Data Report NV-86-1, NV-87-1, NV-89-1.

REFERENCES

Chilton Engineering. 1992-1993. Hydrologic Monitoring Thousand Springs Creek for Woodward-Clyde Consultants, Inc.; Elko, Nevada.

McDonald, M.G., and A.W. Harbaugh. 1988. A Modular Three-Dimensional Finite-Difference Ground-Water Flow Model, Modeling Techniques, Book 6, Chapter A1.

Prudic, David E. 1989. Documentation of a Computer Program to Simulate Stream-Aquifer Relations Using a Modular, Finite-Difference, Ground-Water Flow Model, U.S. Geological Survey, Open-File Report 88-729.

U.S. Geological Survey. 1988-97. Water Resources Data, Nevada, U.S. Geological Survey Water-Data Report NV-96-1, NV-97-1, NV-98-1.

Table 1. ESTIMATED RANGE OF AVERAGE SEASONAL FLOWS BY STREAM SEGMENT, MILLION CUBIC FEET/DAY

Segment	Irrigation Season[1]		Non-Irrigation Season	
	Maximum	Minimum	Maximum	Minimum
I	0.1	0.04	3.17	1
IIa	0.12	0.003	3.28	1.2
IIb	0.16	0.04	3.26	1.2
III	0.06	0.06	0.43	0.43

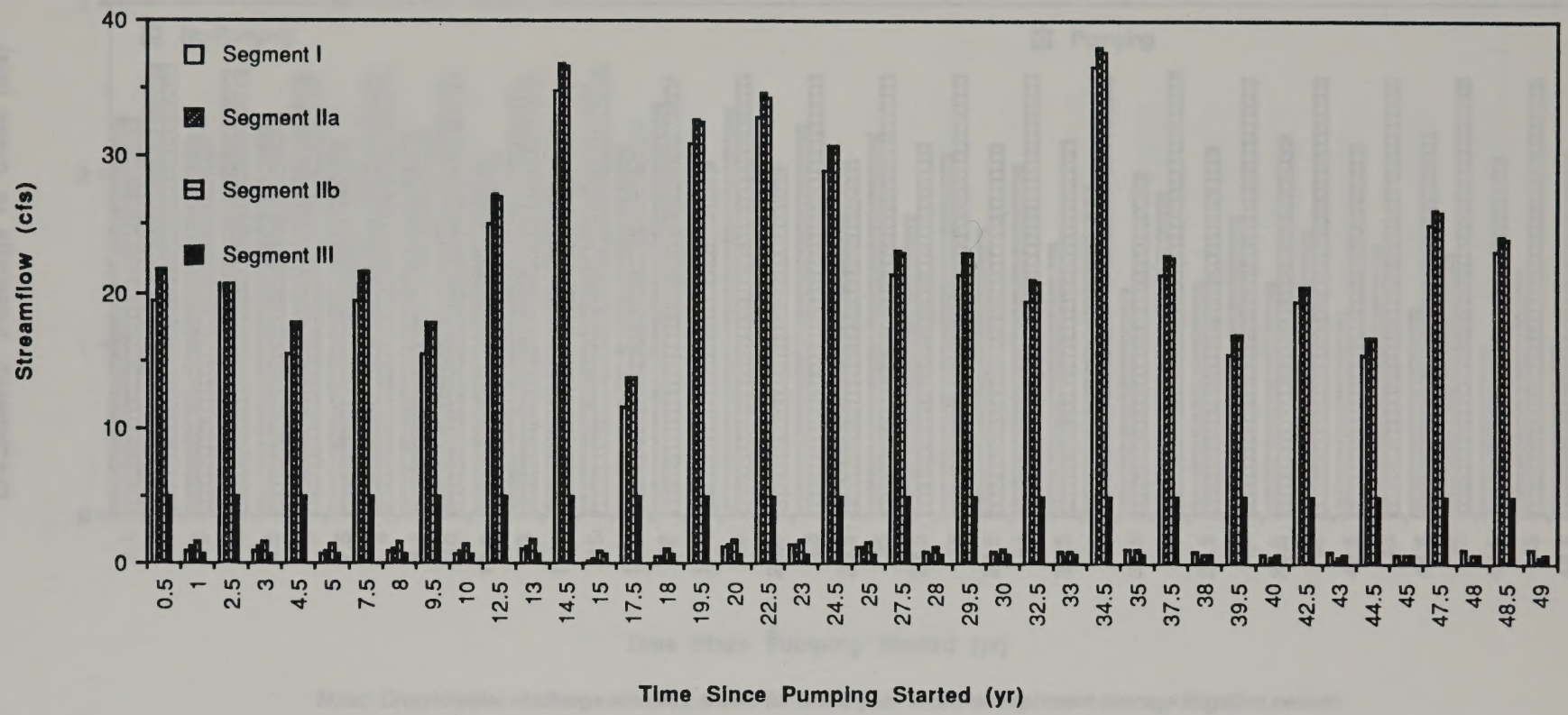
[1] Flow in each segment is after subtracting the irrigation requirement within the segment, or 90 percent of the flow entering the segment when total available flow is less than the irrigation requirement.

Table 2. DECREASES IN TOTAL AVERAGE FLOW IN CREEK AND IN GROUNDWATER DISCHARGE TO CREEK, 1,000 CU FT/DAY [cfs]

Segment	Average Surface Water Inflow	Average Pre-Pumping GW Discharge to Creek	Decrease in GW Discharge	Percent Decrease in Total Average Inflow	Percent Decrease in GW Discharge
I	977 [11.3]	205 [2.4]	106 [1.2]	10	48
IIa	1057 [12.2]	17 [0.2]	6 [0.07]	1	31
IIb	1072 [12.4]	90 [1.0]	1 [0.01]	0	1
III	246 [2.8]	279 [3.2]	11 [0.13]	4	4
Total		411 [4.8]	124 [1.4]		30

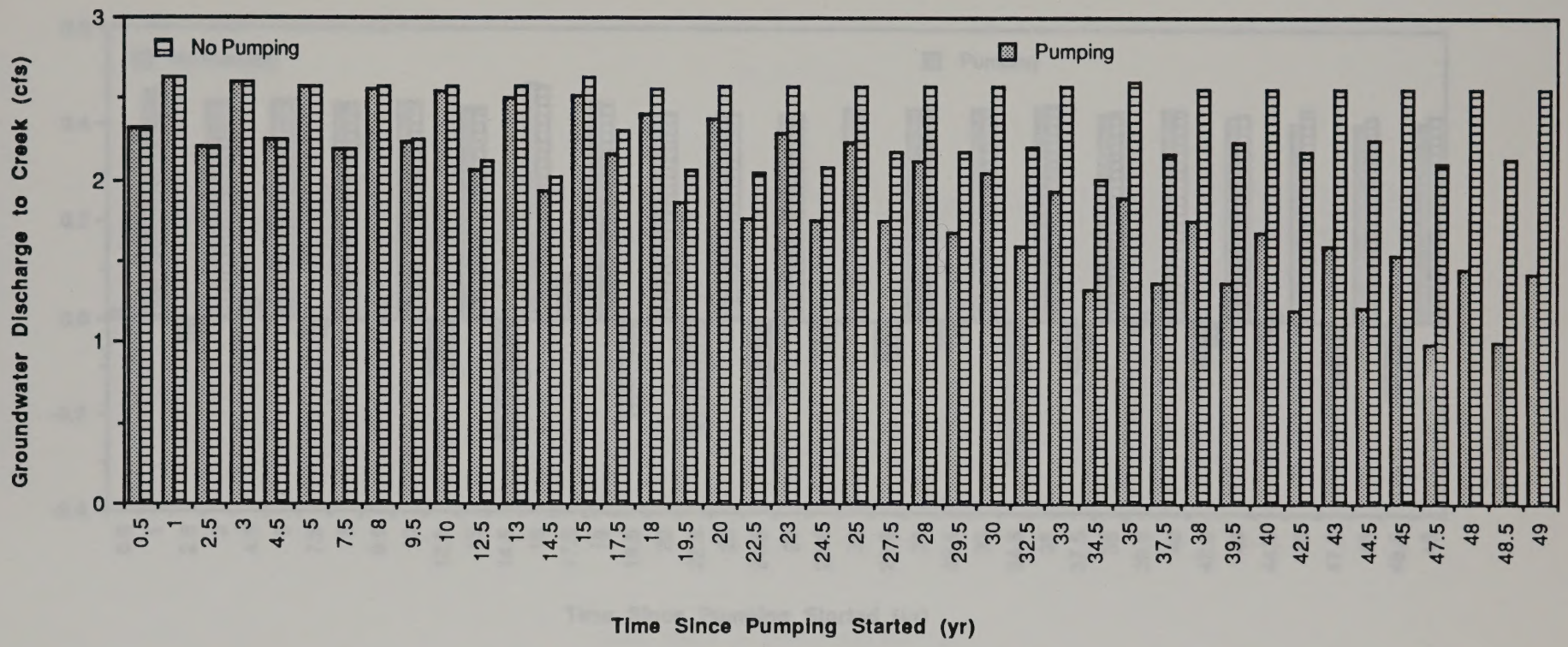
Table 3. DECREASE IN EVAPOTRANSPIRATION (ET) FROM AREAS OF SHALLOW WATER TABLE, 1000 CU FT/DAY [cfs]

Segment	Average Pre-Pumping ET	Decrease in ET	% Decrease in Pre-Pumping ET
I	198 [2.3]	17 [0.2]	9
IIa	73 [0.8]	9 [0.1]	12
IIb	52 [0.6]	2 [0.02]	4
III	221 [2.6]	8 [0.1]	4
Total	544 [6.3]	36 [0.45]	7



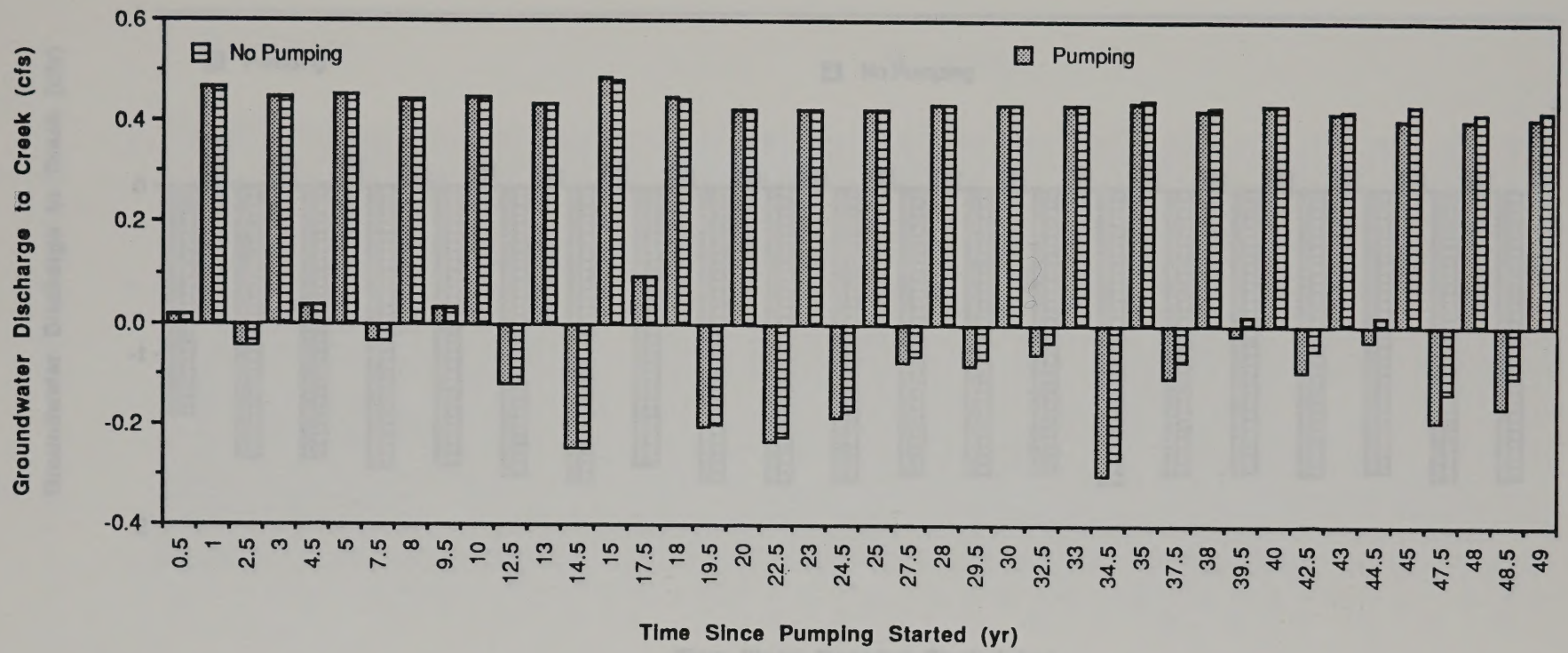
Note: Streamflow amounts shown for whole year ordinates represent average irrigation season flows whereas amounts shown at half-year ordinates represent average non-irrigation season flows

Figure 1. Simulated Streamflow Entering Segments



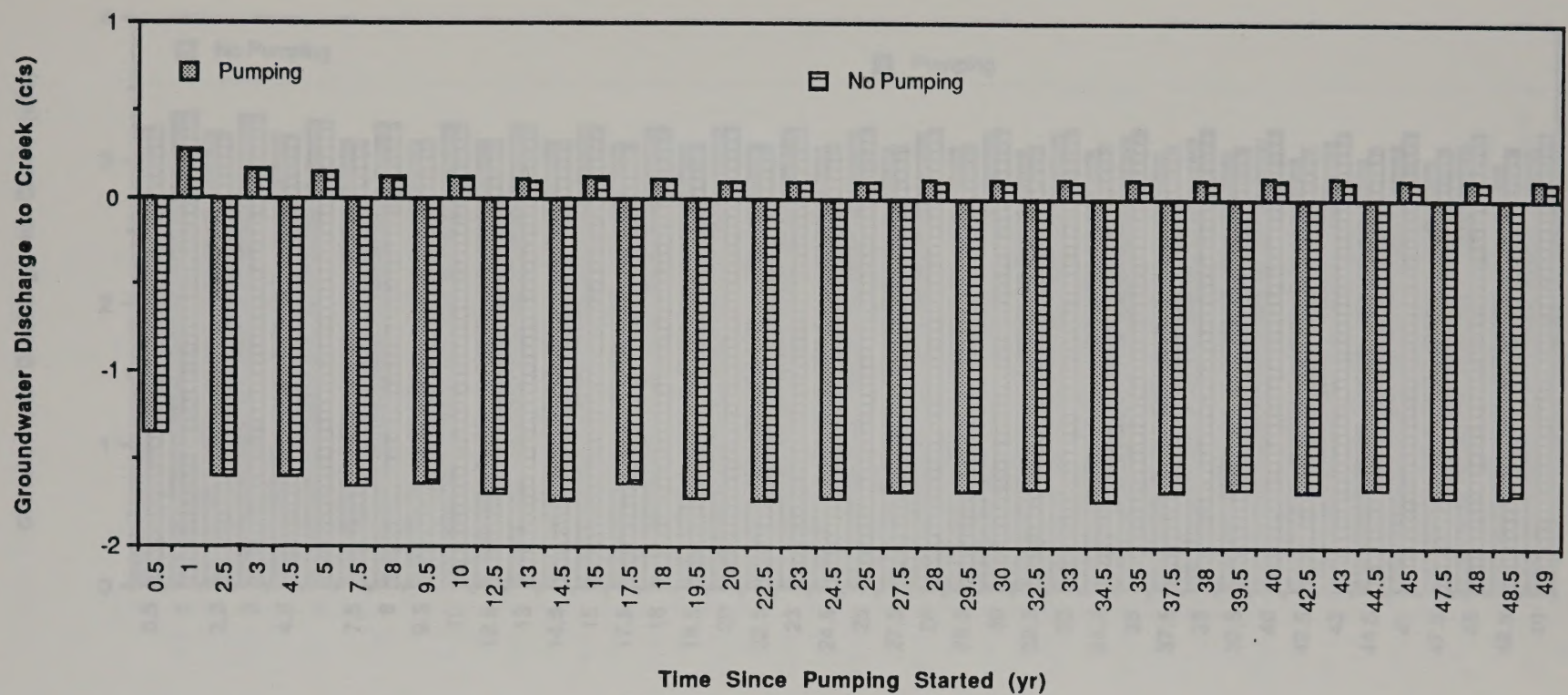
Note: Groundwater discharge amounts shown for whole year ordinates represent average irrigation season amounts whereas amounts shown at half-year ordinates represent average non-rrigation season amounts

Figure 2. Simulated Groundwater Discharge to Segment I



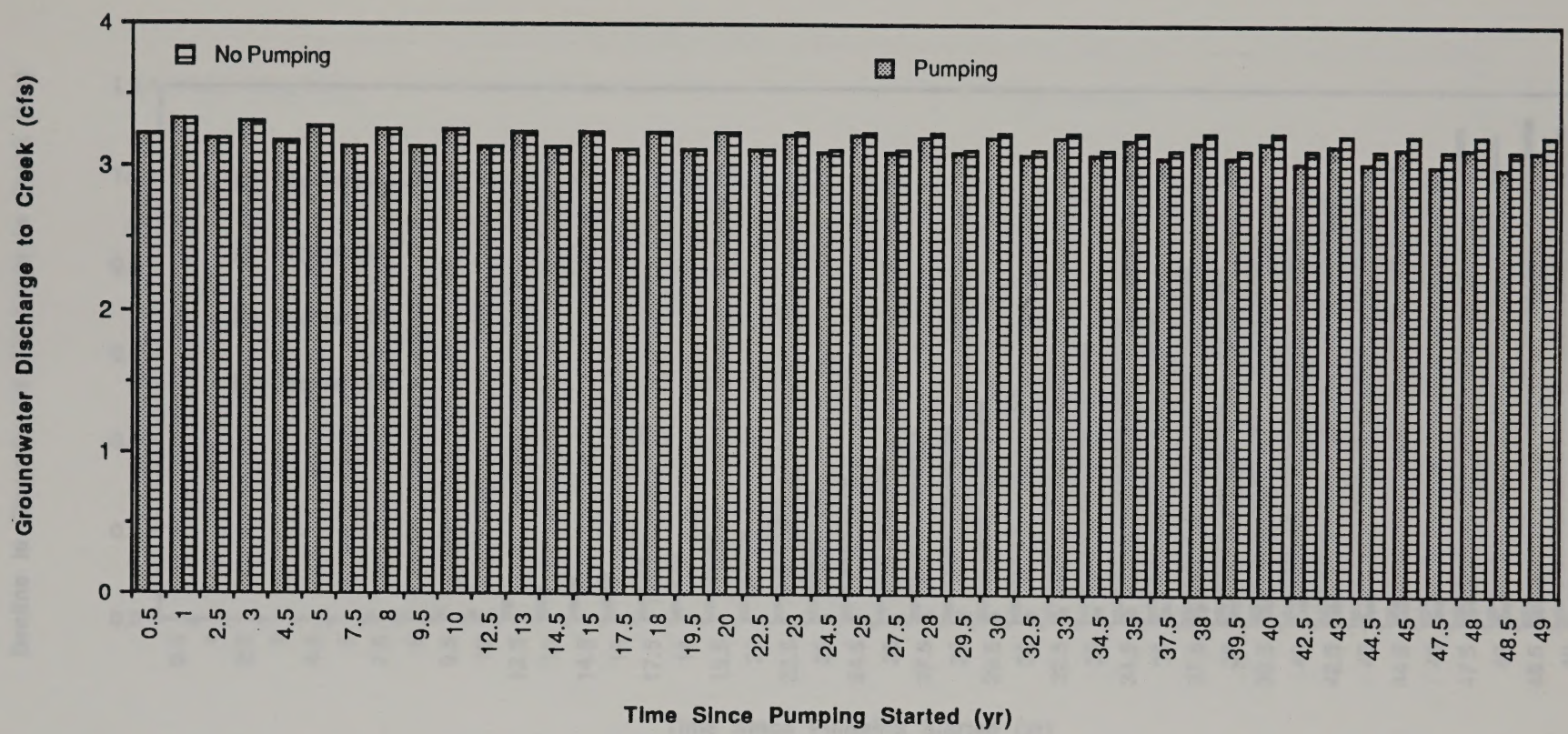
Note: Groundwater discharge amounts shown for whole year ordinates represent average irrigation season amounts whereas amounts shown at half-year ordinates represent average non-irrigation season amounts

Figure 3. Simulated Groundwater Discharge to Segment IIa



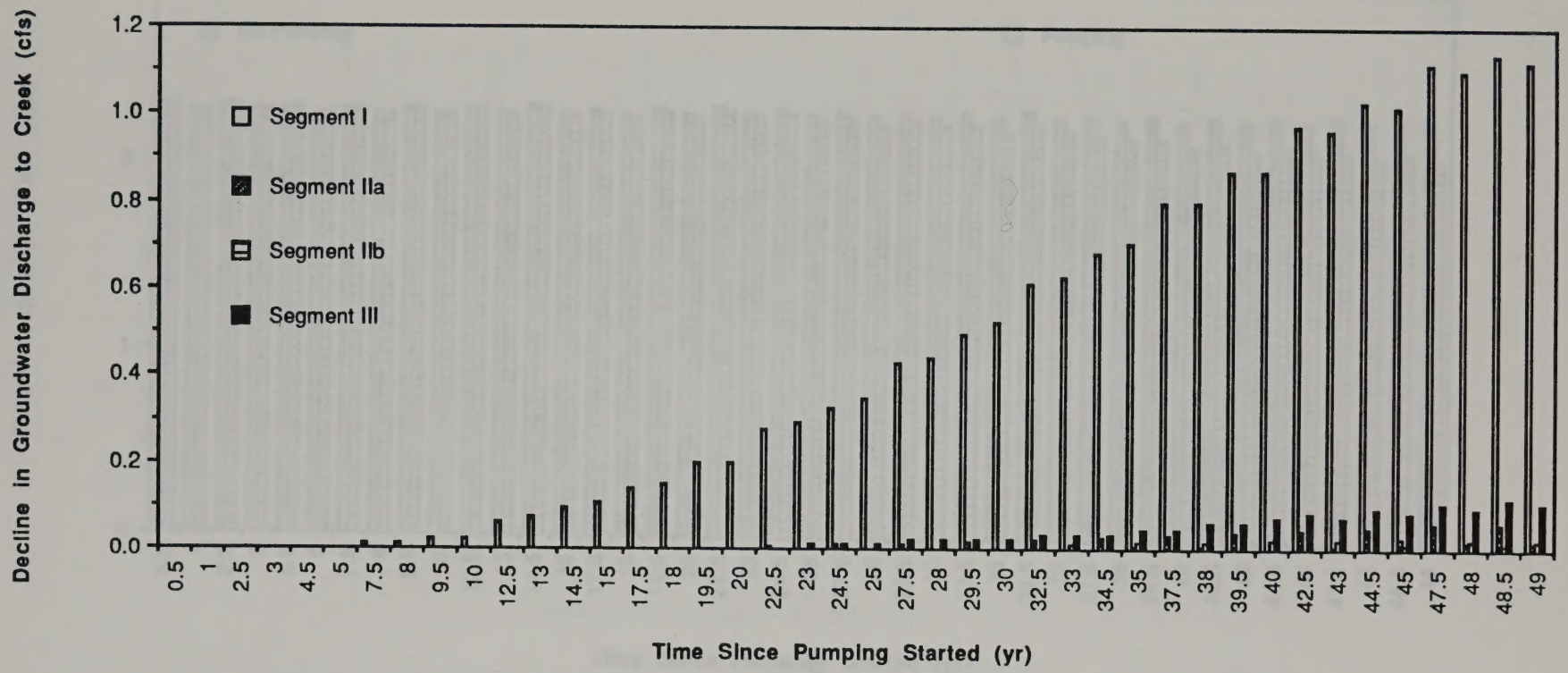
Note: Groundwater discharge amounts shown for whole year ordinates represent average irrigation season amounts whereas amounts shown at half-year ordinates represent average non-irrigation season amounts

Figure 4. Simulated Groundwater Discharge to Segment IIb



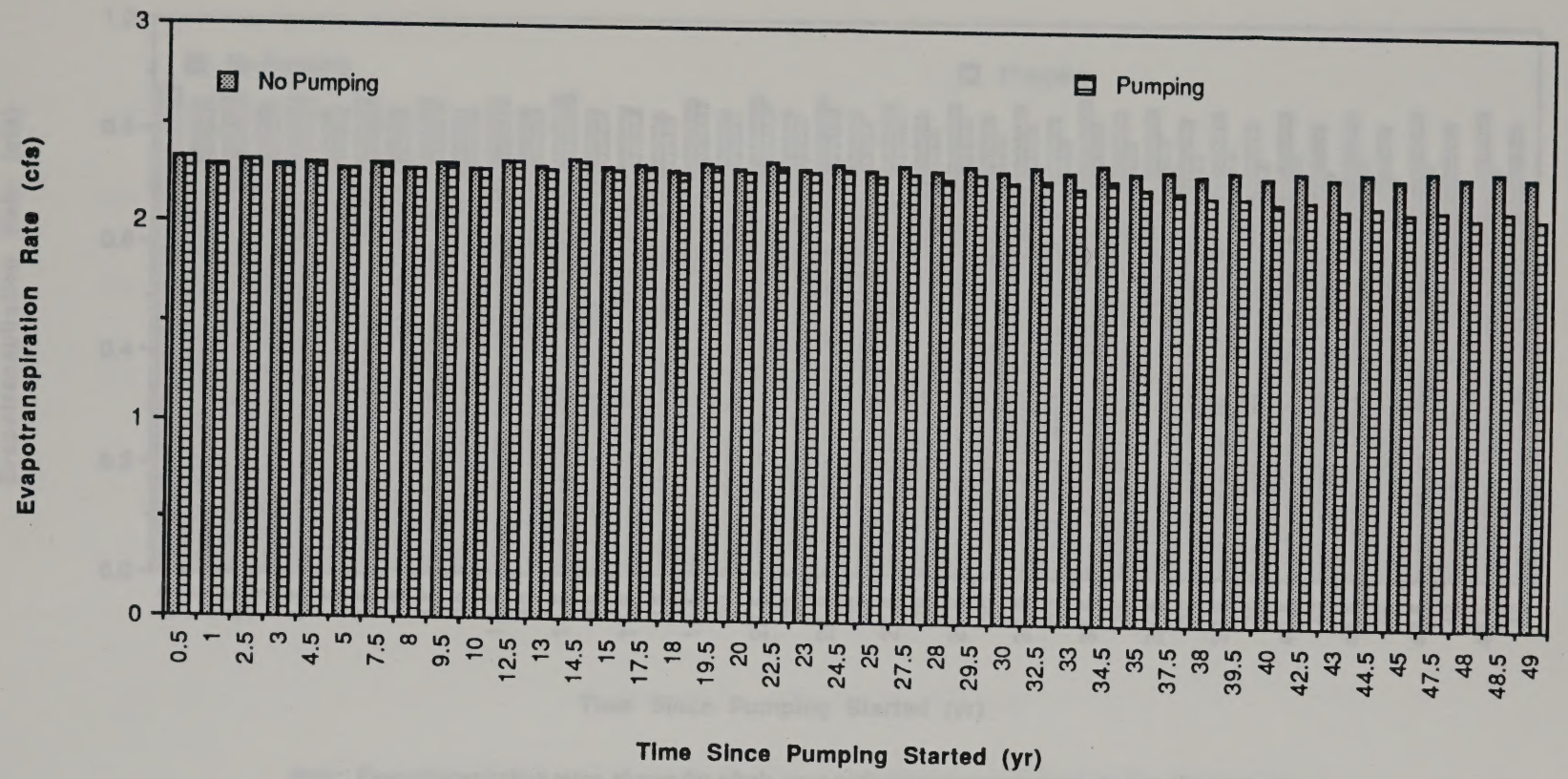
Note: Groundwater discharge amounts shown for whole year ordinates represent average irrigation season amounts whereas amounts shown at half-year ordinates represent average non-irrigation season amounts

Figure 5. Simulated Groundwater Discharge to Segment III



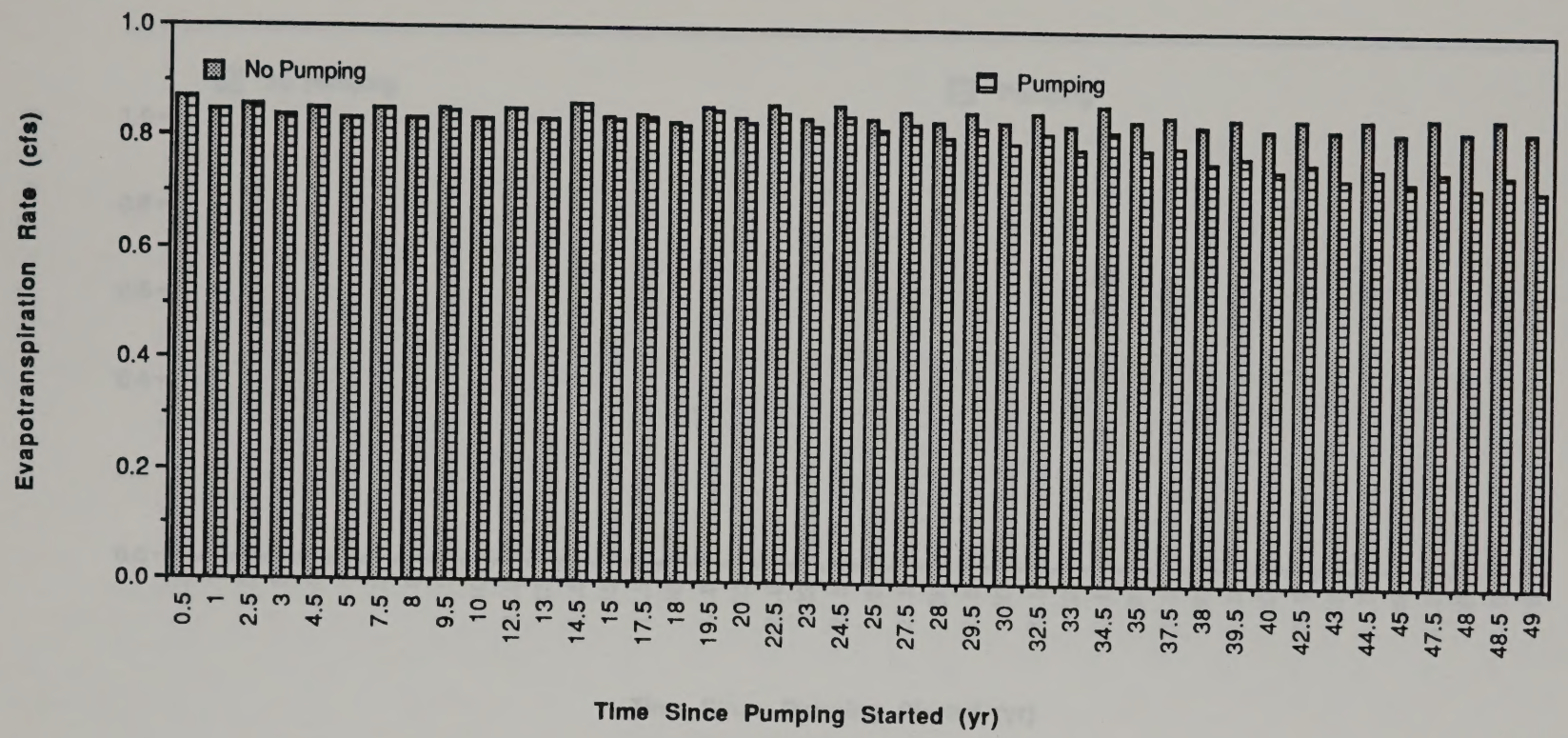
Note: Groundwater discharge amounts shown for whole year ordinates represent average irrigation season amounts whereas amounts shown at half-year ordinates represent average non-irrigation season amounts

Figure 6. Simulated Decline in Groundwater Discharge to the Creek



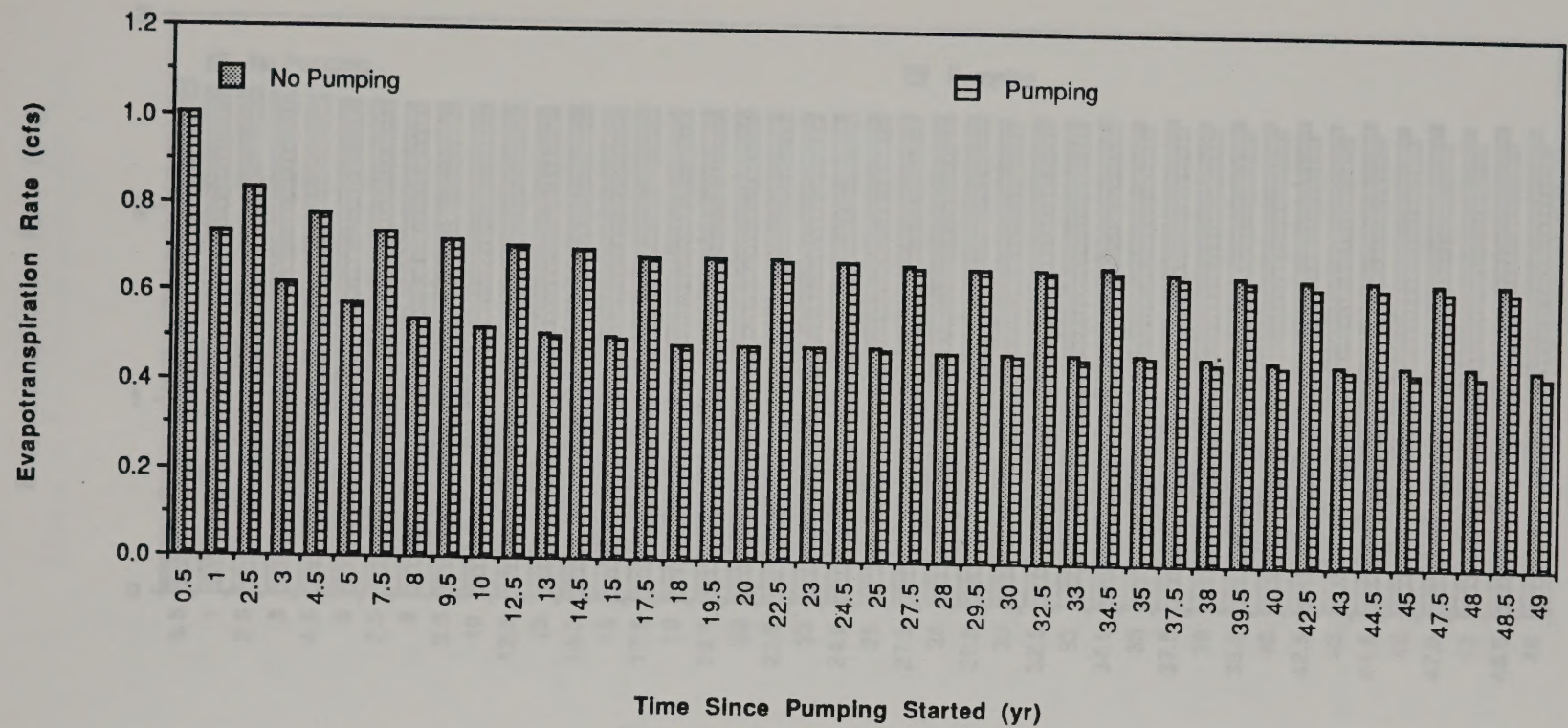
Note: Evapotranspiration rates shown for whole year ordinates represent average irrigation season rates whereas rates shown at half-year ordinates represent average non-irrigation season rates

Figure 7. Simulated Evapotranspiration Rate in Segment I



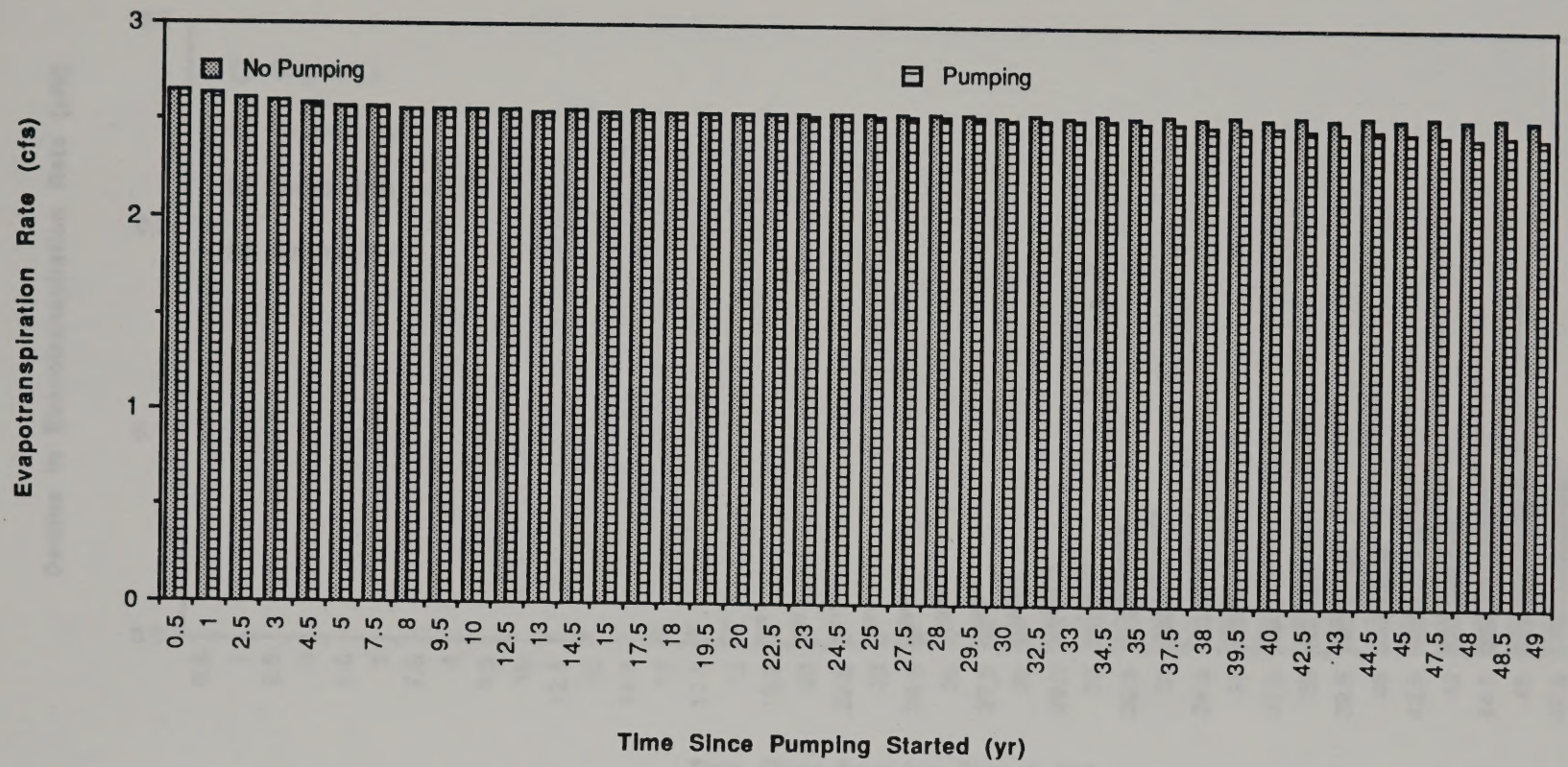
Note: Evapotranspiration rates shown for whole year ordinates represent average irrigation season rates whereas rates shown at half-year ordinates represent average non-irrigation season rates

Figure 8. Simulated Evapotranspiration Rate in Segment IIa



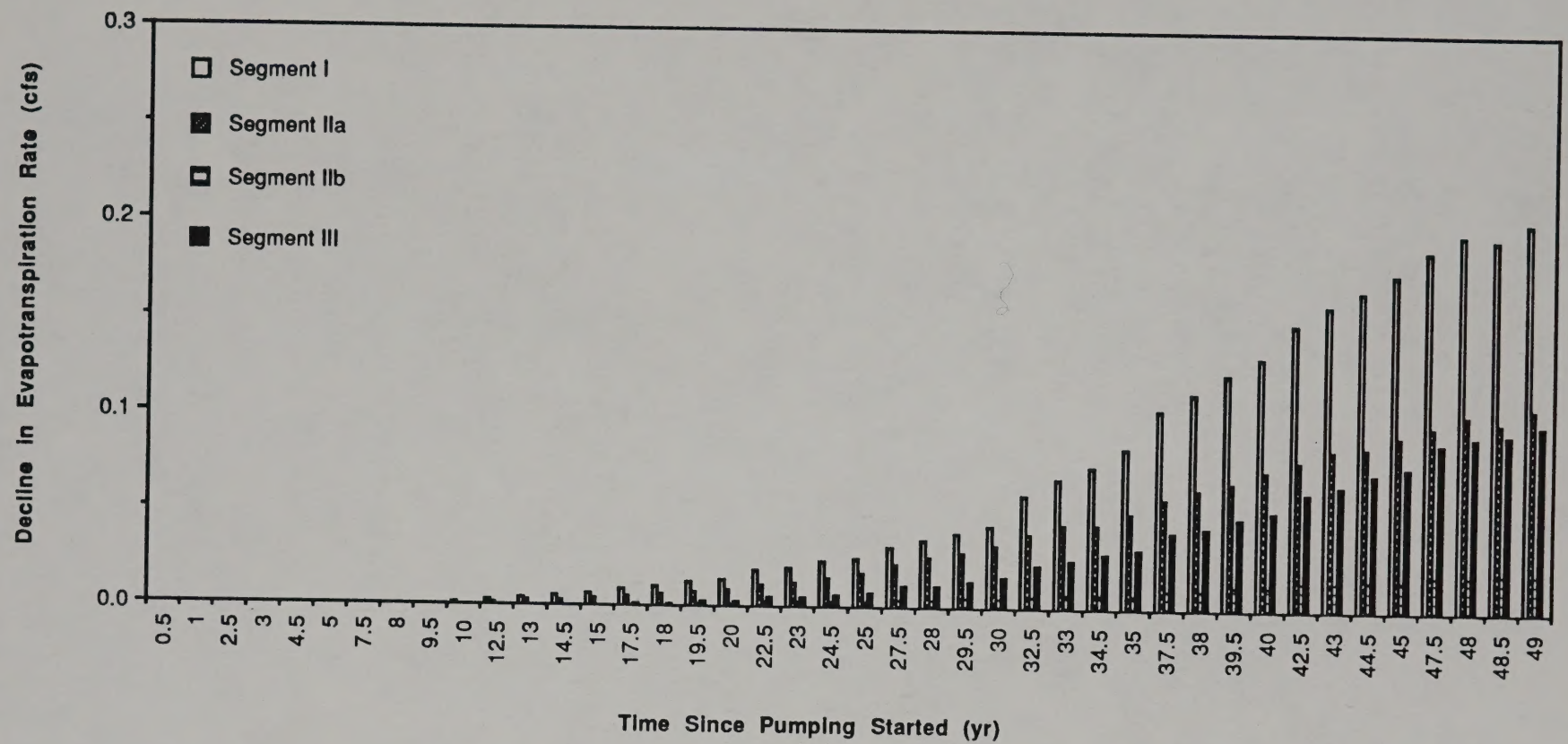
Note: Evapotranspiration rates shown for whole year ordinates represent average irrigation season rates whereas rates shown at half-year ordinates represent average non-irrigation season rates

Figure 9. Simulated Evapotranspiration Rate in Segment IIb



Note: Evapotranspiration rates shown for whole year ordinates represent average irrigation season rates whereas rates shown at half-year ordinates represent average non-irrigation season rates

Figure 10. Simulated Evapotranspiration Rate in Segment III



Note: Evapotranspiration rates shown for whole year ordinates represent average irrigation season rates whereas rates shown at half-year ordinates represent average non-irrigation season rates

Figure 11. Simulated Decline in ET Rate